ISSC - Interplanetary Small Satellite Conference

May 1, 2023

Navigation of *LICIACube*: Challenges and Lessons Learned

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CubeSats in DeepSpace

- The CubeSat is a standard for microsatellites introduced in the 2000s by the CalPoly.
  - Standard size is 1U multiples (10x10x10 cm).
- CubeSats gained a strong heritage for near-Earth applications increasing reliability and performances.
  - Recent use in deep space.

2018

MarCOs
NASA's *InSight* mission to MARS

2022

LICIACube
ASI's mission to Didymos in support of NASA's DART

SLS released CubeSats
Many CubeSats released in a cis-lunar orbit

2024

Juventas & Milani
ESA's Hera mission to Didymos

Navigation - Overview

Navigation objectives:

- Deliver spacecraft into the desired location subject to the constraints of the spacecraft and ground system design.
  - Orbit determination (OD) and Guidance/Flight Path Control (FPC).
- Maintain ephemeris knowledge to the level required to acquire spacecraft signal from Earth at any time.
- Estimate spacecraft trajectory and associated parameters along their covariance.
  - Compute trajectory correction maneuvers.

Mission Tasks:

- Covariance studies, Operations and Reconstruction.

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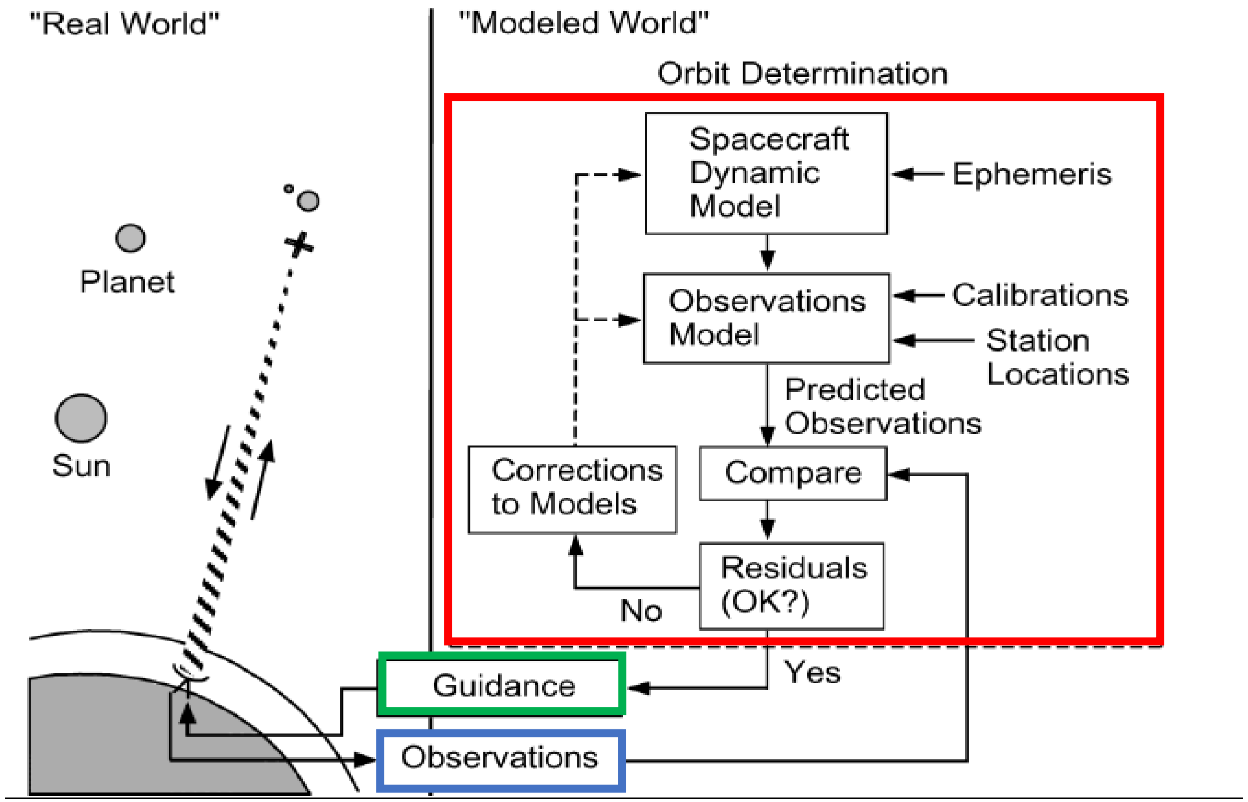
- Requirements design - Covariance studies - Other	- Navigation Operations - Covariance studies	- Trajectory Reconstruction

Thornton and Border (2003)



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LICIACube - Technical specifications

- 6U CubeSat, launch mass 12.98 kg.
- Size ~30x20x10 cm central body with 2 additional extensible solar panels ~30x40 cm each.
- X/X IRIS coherent transponder with 4 patched antennas:
  - Top side: 6dB Rx, 22dB Tx.
  - Bottom side: 6dB Rx, 12dB Tx.
- VaCCO thruster:
  - R-236fa cold gas.
  - 1.236 kg embarked fuel (~37 m/s).

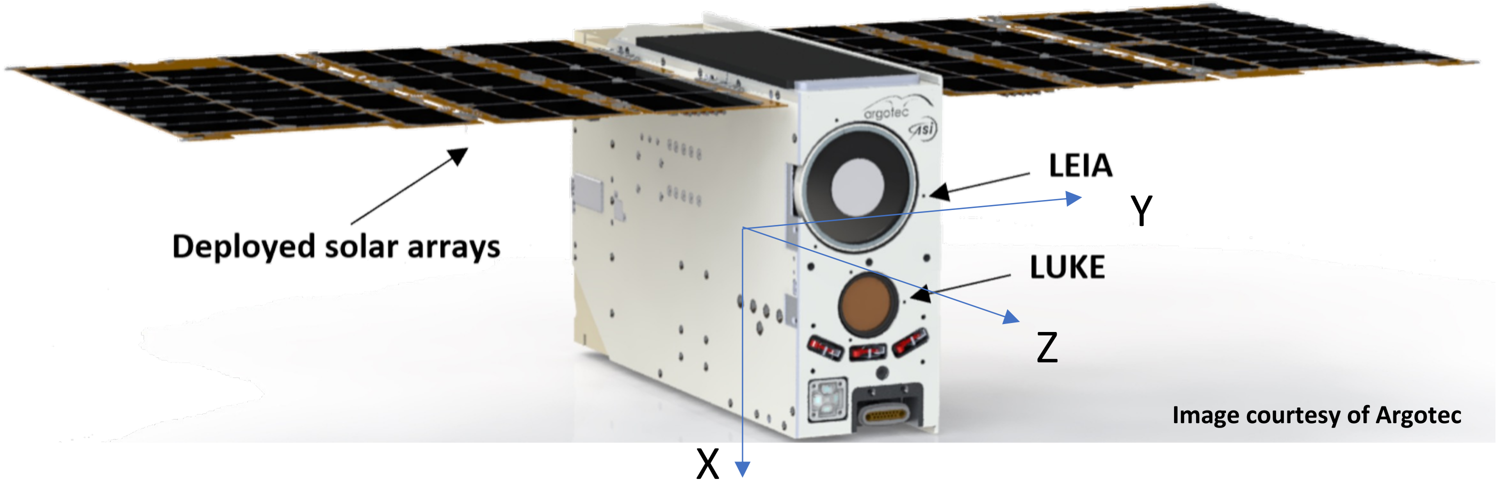
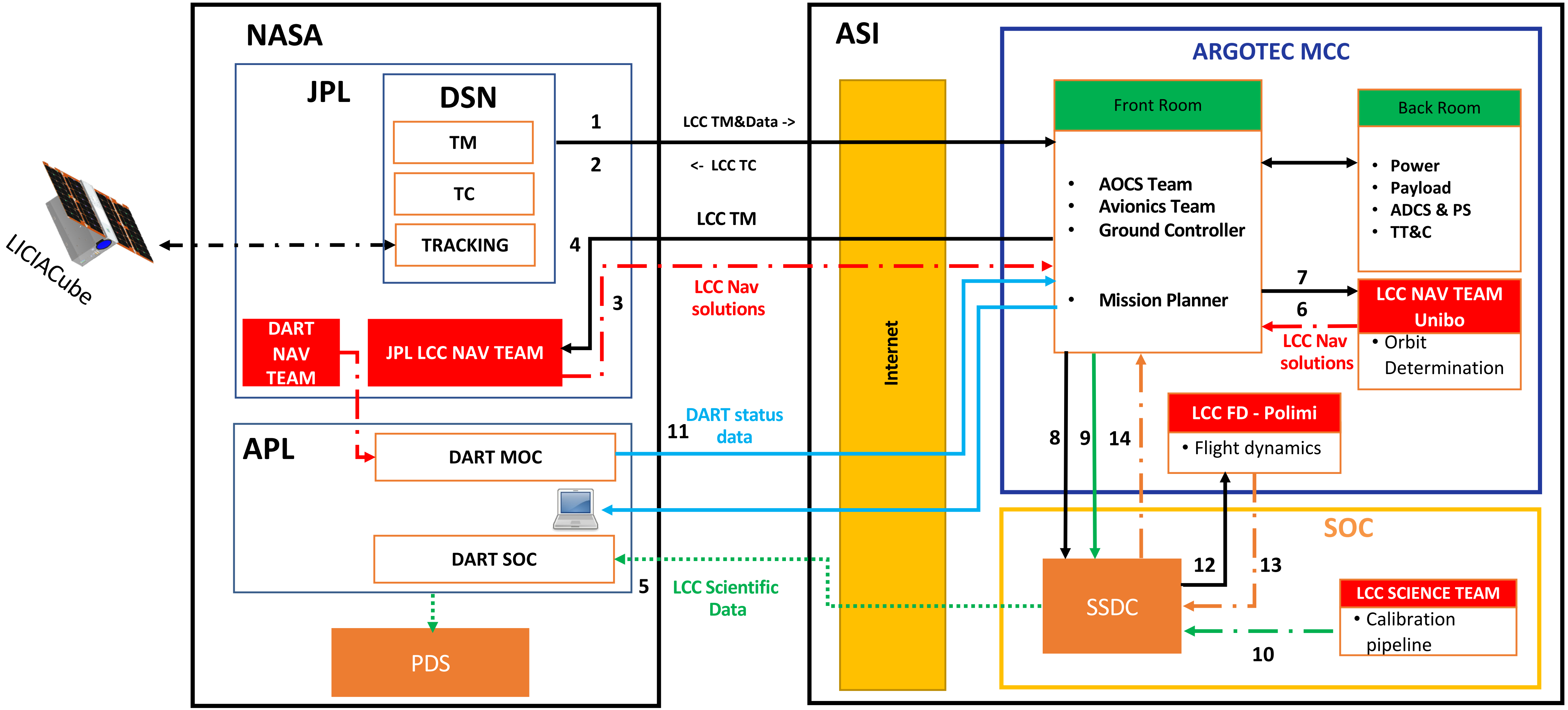


Image courtesy of Argotec

- Payload:

Camera	Focal length	dFOV	Sensor	Sensor size	Color filter
LEIA	222.45 mm	±2.06°	CMOS CMV 4000	2048x2048px	Panchromatic 400-900mm
LUKE	70.45 mm	±5.00°	CMOS CMV 2000	2048x1088 px	Bayer filter

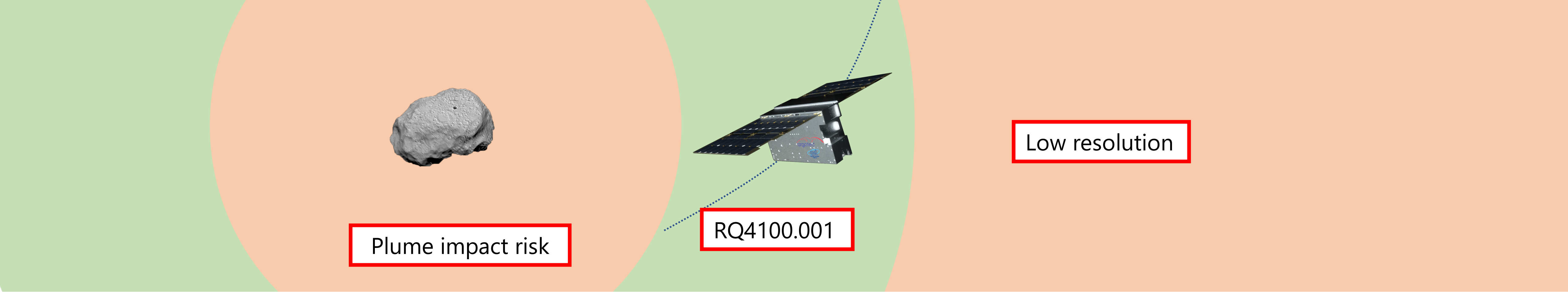
Navigation of LICIACube –Interfaces



LICIACube requirements

NAVIGATION Requirements	
RQ4100.001	The S/C to Dimorphos distance at C/A shall be $39.9\ km \leq d_{\pm 3\sigma} \leq 80\ km$
RQ4100.002	The Dimorphos pointing uncertainty at C/A-200s shall be $3\sigma_{\vartheta} \leq \frac{FOV_{LEIA}}{2} \approx 1.46\ deg$
RQ4100.003	The Earth (DSN station) to S/C pointing uncertainty shall be $3\sigma_{\alpha} \leq 0.017\ deg$ *
RQ4100.004	The Dimorphos C/A delay time with respect to DART impact shall be $\Delta t_{3\sigma} \leq 200\ sec$
RQ4100.005	The Sun Phase Angle (SPA) at the C/A shall be $45\ deg \leq SPA_{\pm 3\sigma} \leq 70\ deg$

* Value for X/X band from: DSN Telecommunications Link Design Handbook, 101 70-m Subnet Telecommunication Interfaces, Rev.G, September 2019



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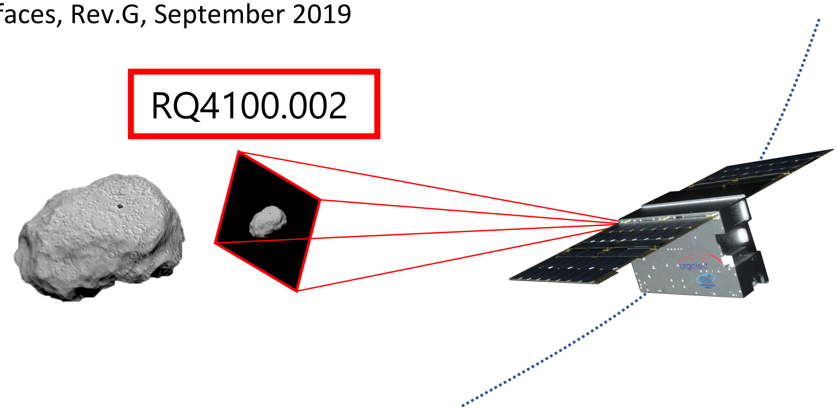

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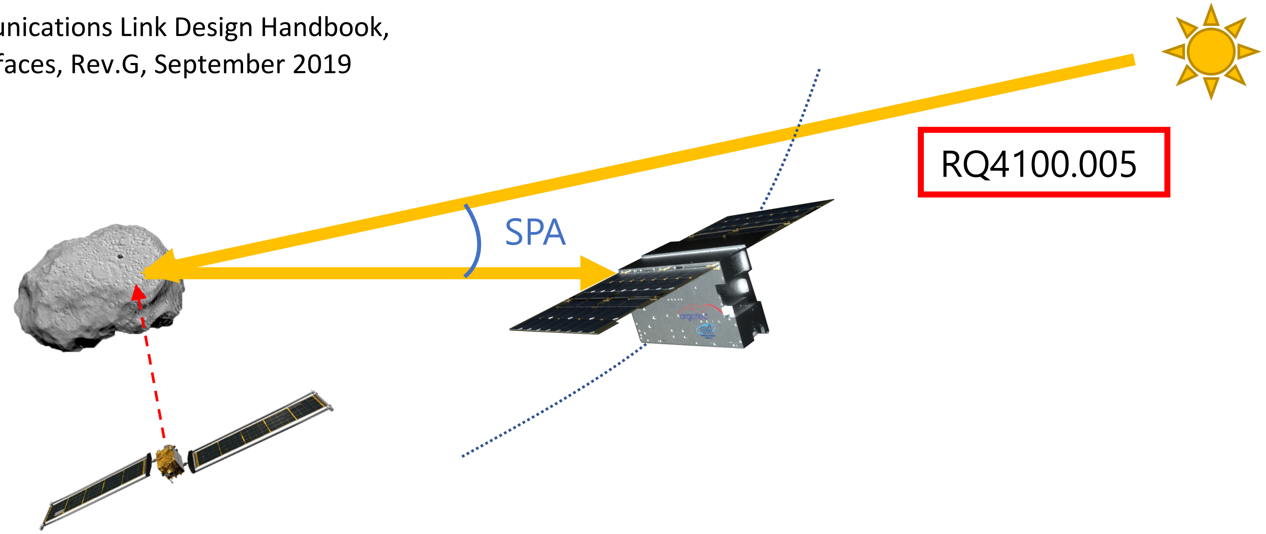
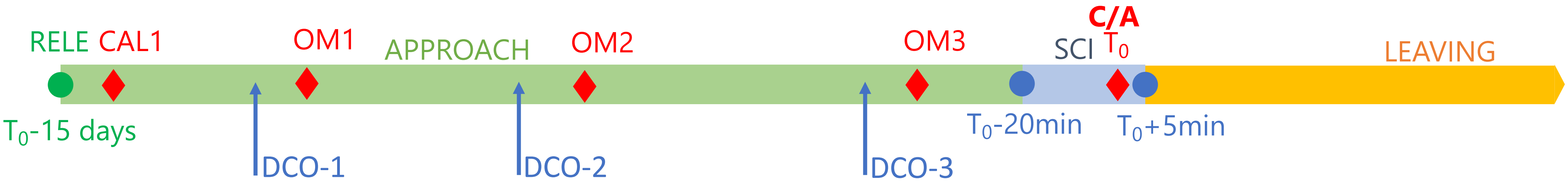


Timeline of *LICIACube* mission

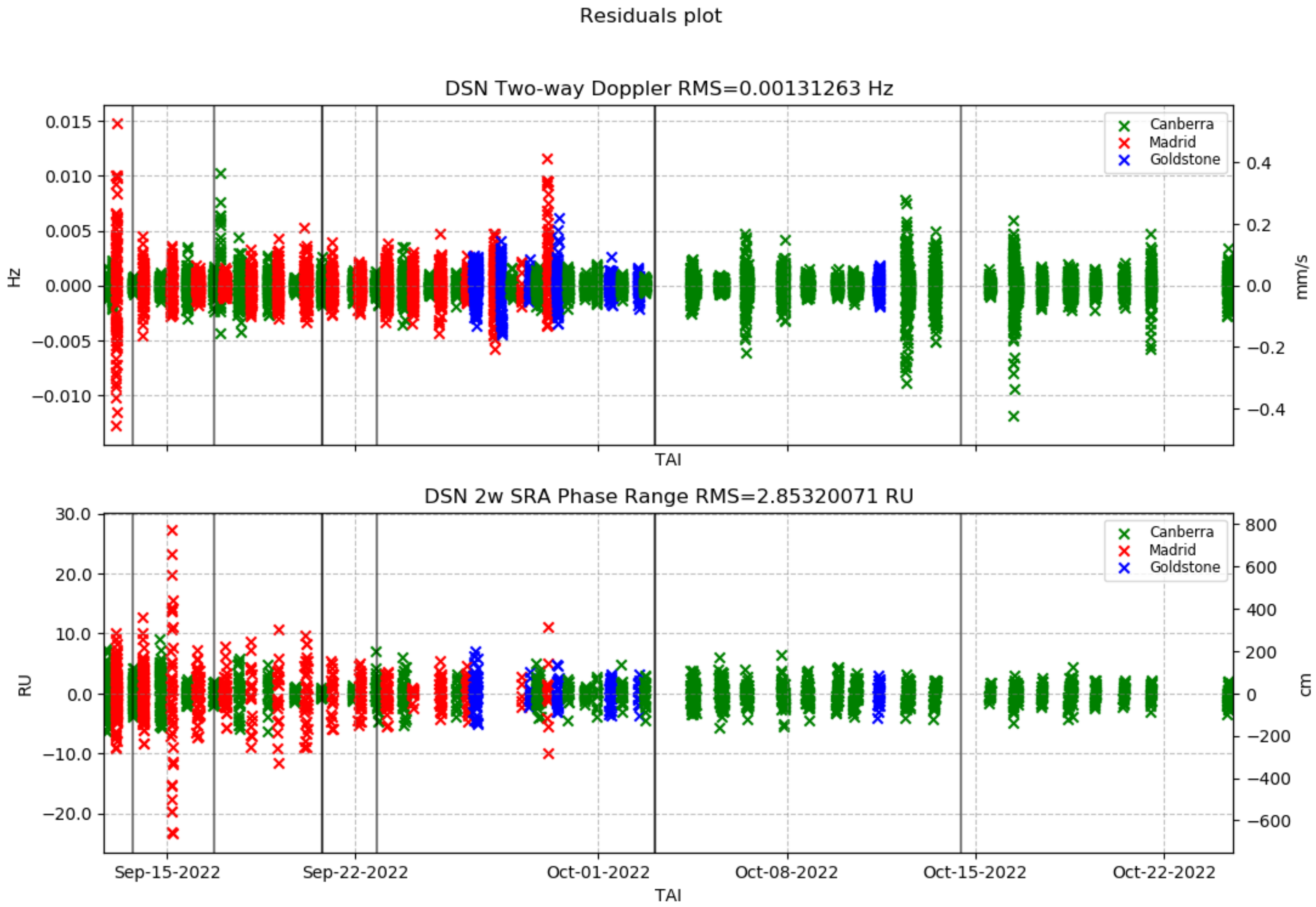
- Release: **<u>15 days before DART impact</u>**.
  - Changed from 10 days to improve the thermal characterization of DART
- C/A:~170 sec after DART impact.



- <u>Maneuvers</u>
  - 1 calibration maneuver (CAL1) to check the thrusters.
  - 1 targeting maneuver (OM1) to address the aimpoint.
  - 2 cleanup maneuvers (OM2/OM3) to clear trajectory deviations during the operations.
- <u>Data Cut-Offs (DCO)</u>
  - Approx. 24/48h between DCO and delivery.
  - At least 1 full pass after each maneuver to gather enough data.

Radiometric Residuals

- **Two-way X-band Doppler data**
  - 2 passes/day 1.5h at 60 seconds count time.
  - Minimum elevation: 15 degrees.
  - Pretty good performance RMS ~50 µm/s.
- **Range data**
  - Pretty good performance RMS ~80 cm.
    - Early in the mission +/- 512 RU jumps. Corrected with the polarity auto-detection.
  - Useful to characterize the F2 Doppler bias.
- **Opnav**
  - Issues with the acquisition of opnavs during the mission.
    - Not used during the mission.
  - 4 Observables used during the reconstruction of the orbit. (Post-operations)
- **Calibrations**
  - Tropospheric.
  - Ionospheric.



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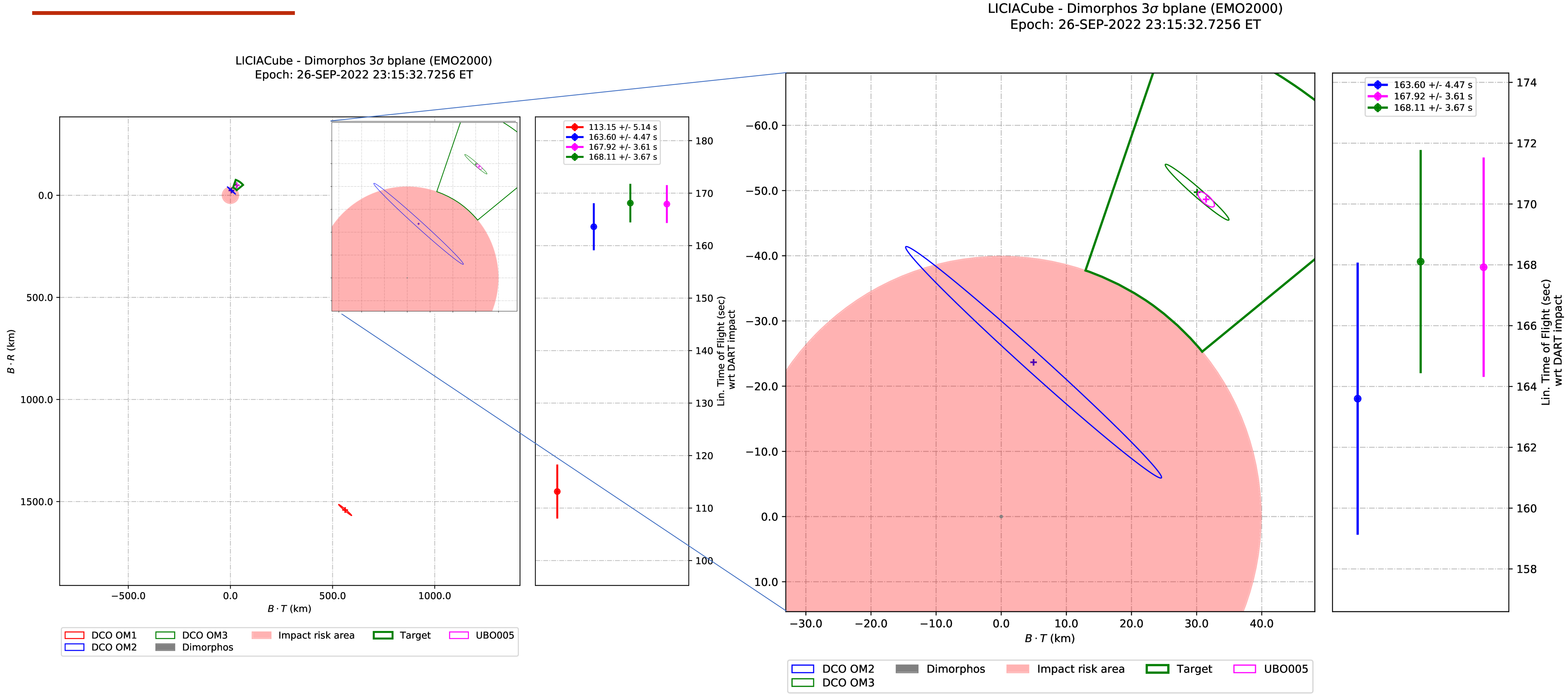
B-plane results



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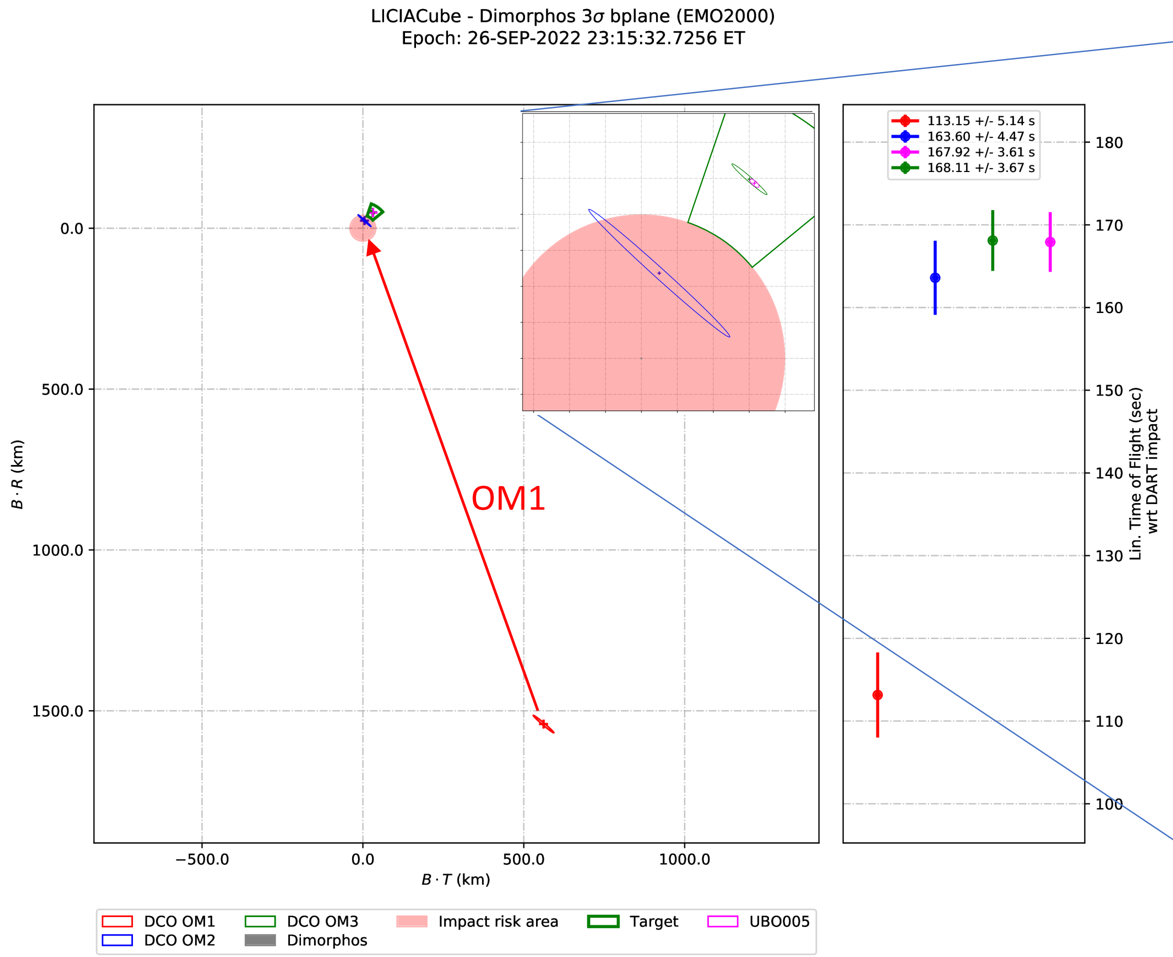

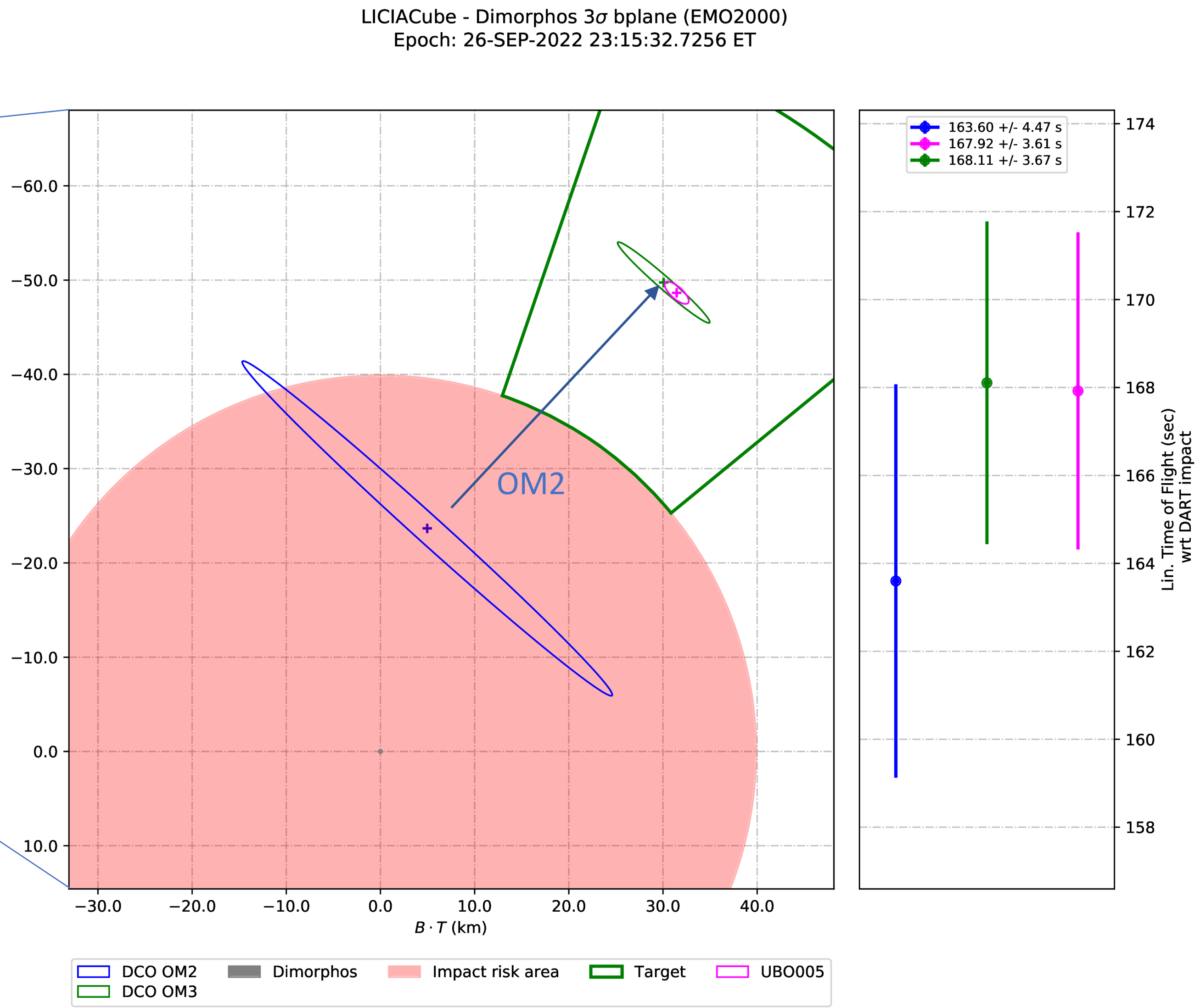

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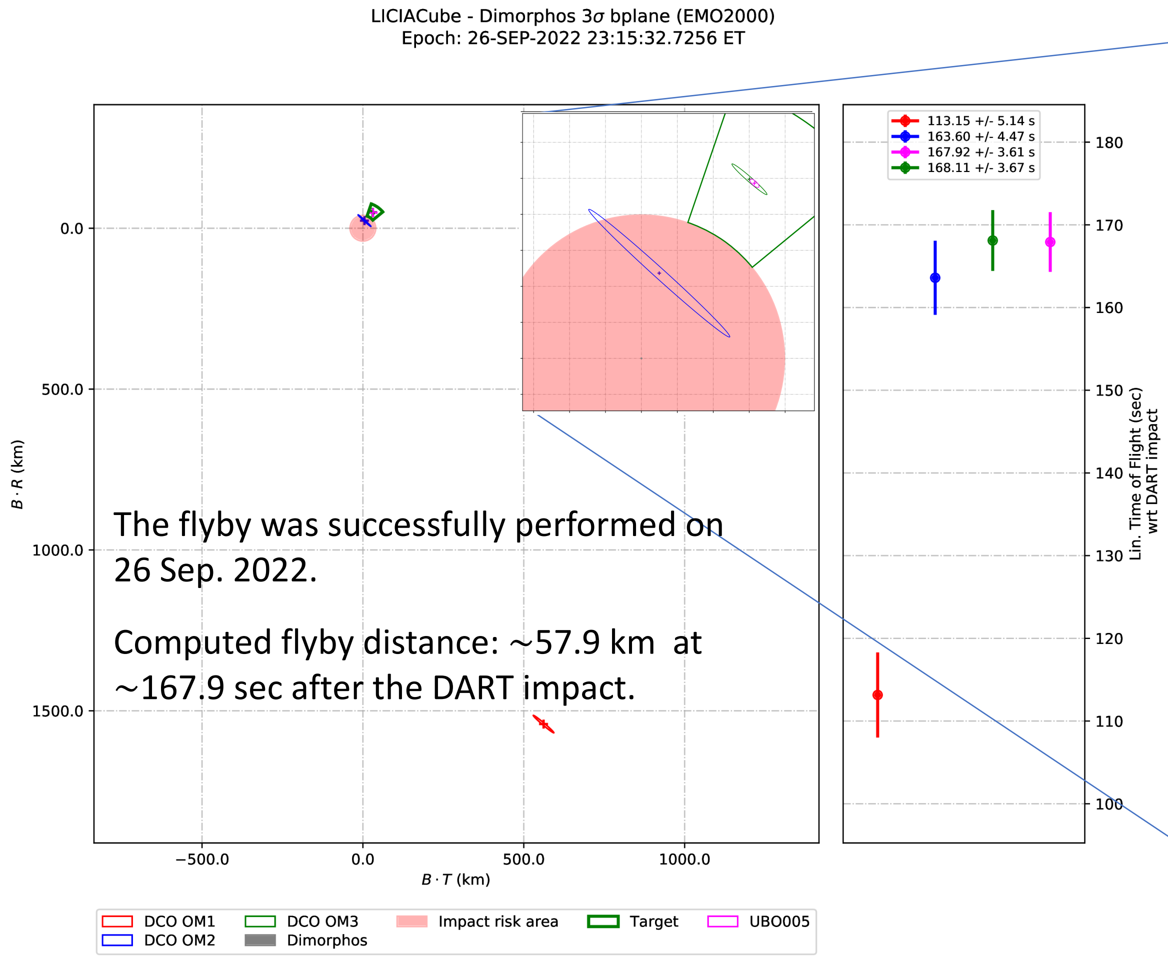
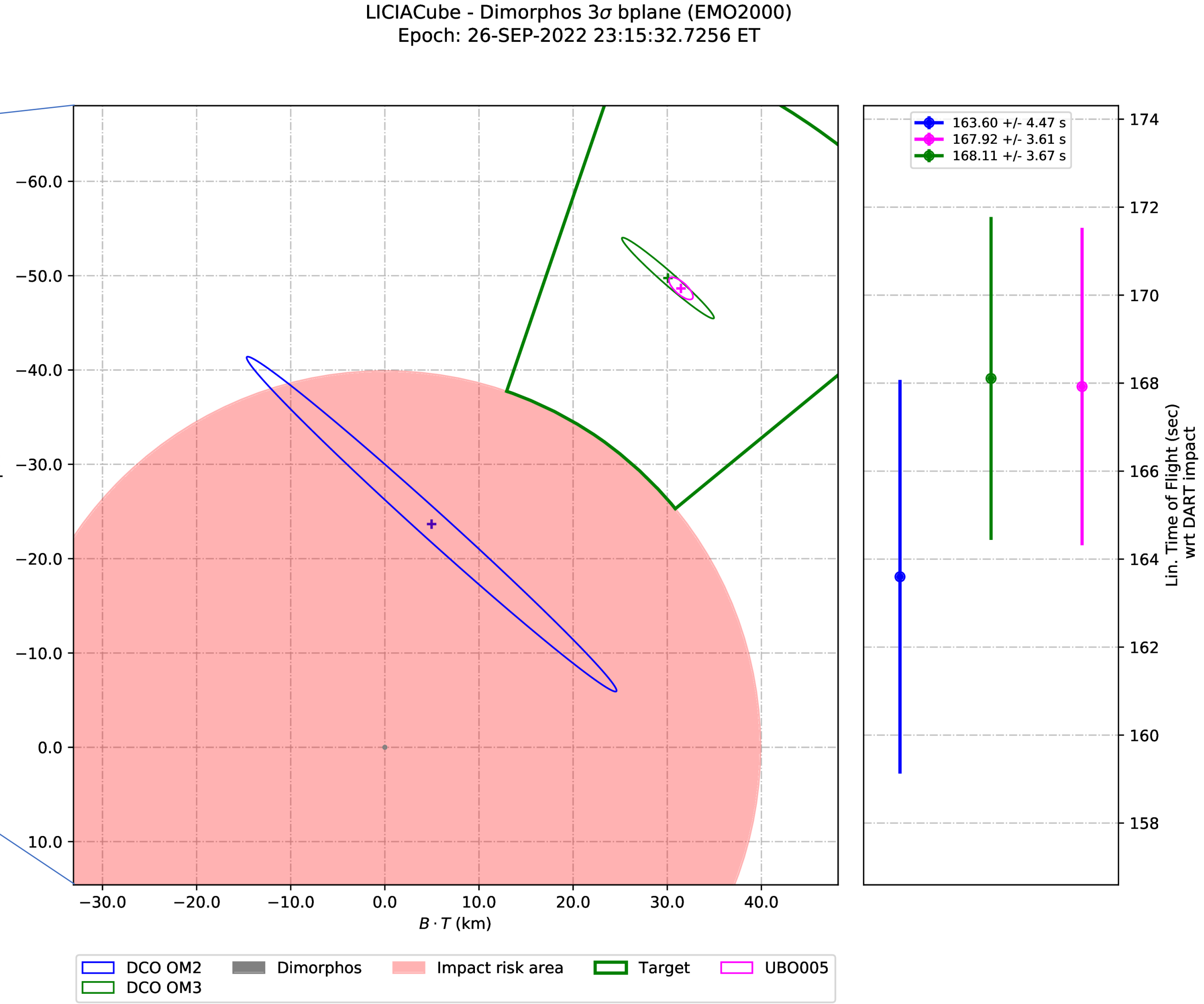


The flyby was successfully performed on 26 Sep. 2022.

Computed flyby distance: ~57.9 km at ~167.9 sec after the DART impact.



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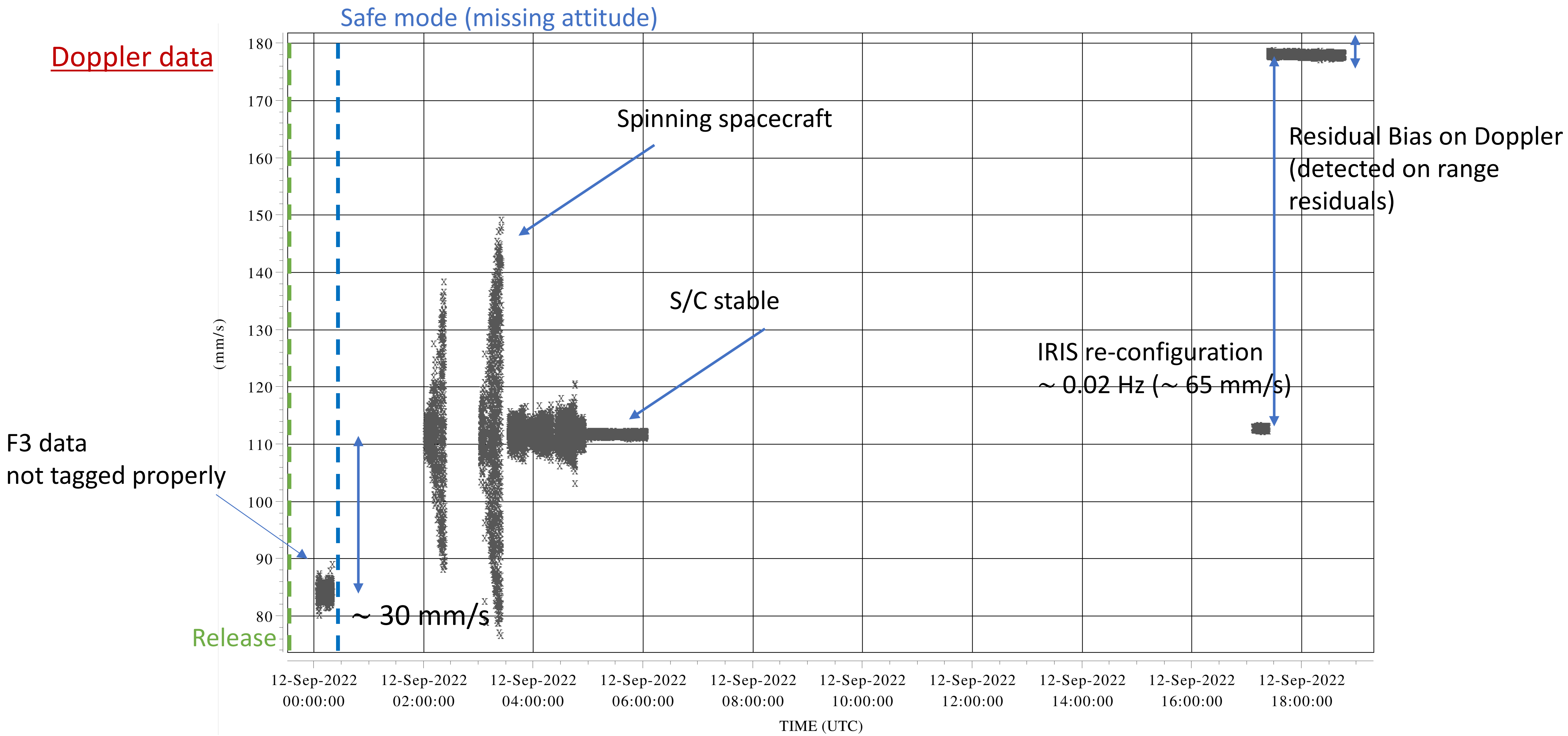
First hours after the release



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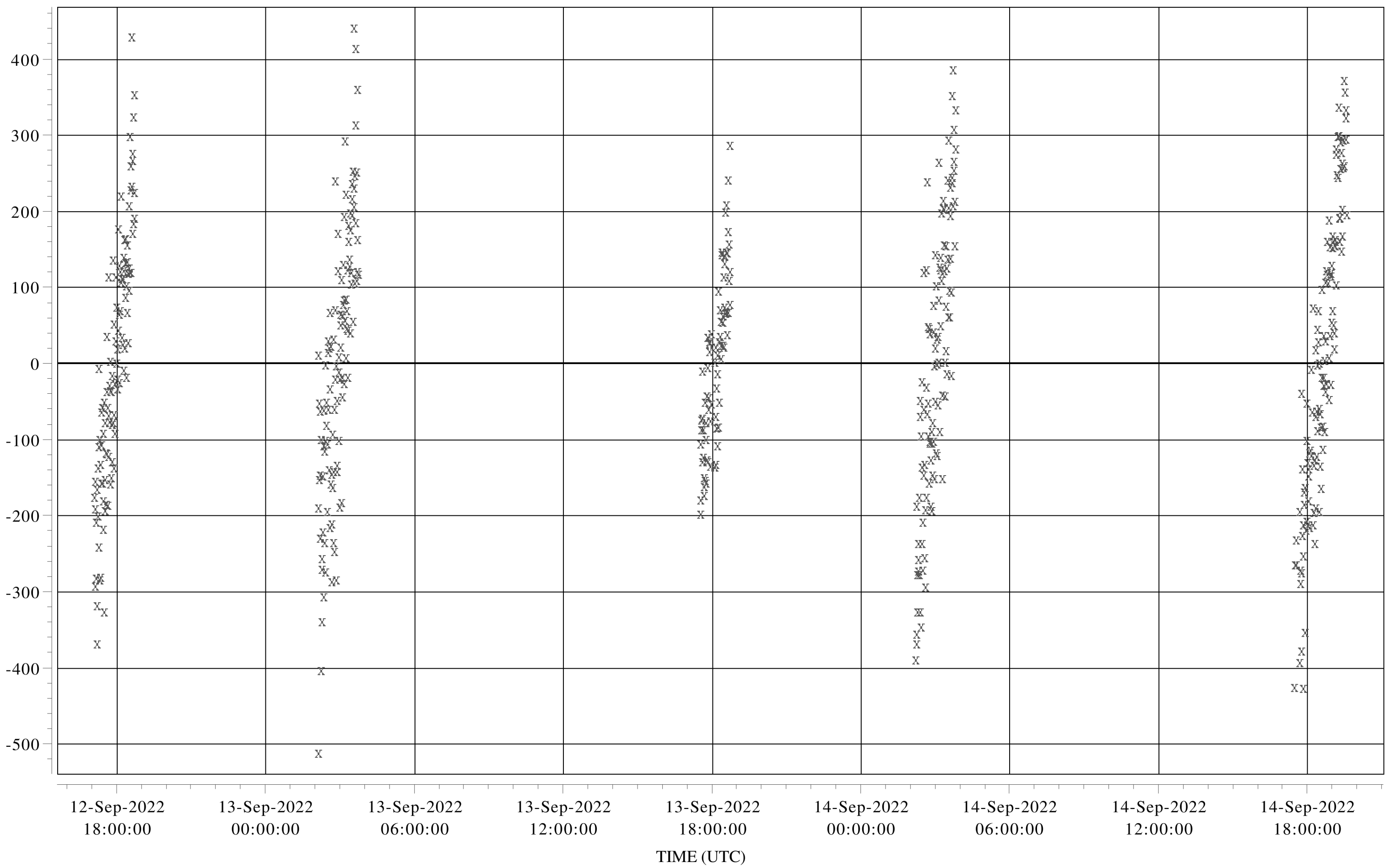
First hours after the release

Range data



Drift on the range passes:

- Explained by residual Doppler Bias.
- IRIS configuration issue.
- Fixed before the execution of OM1.

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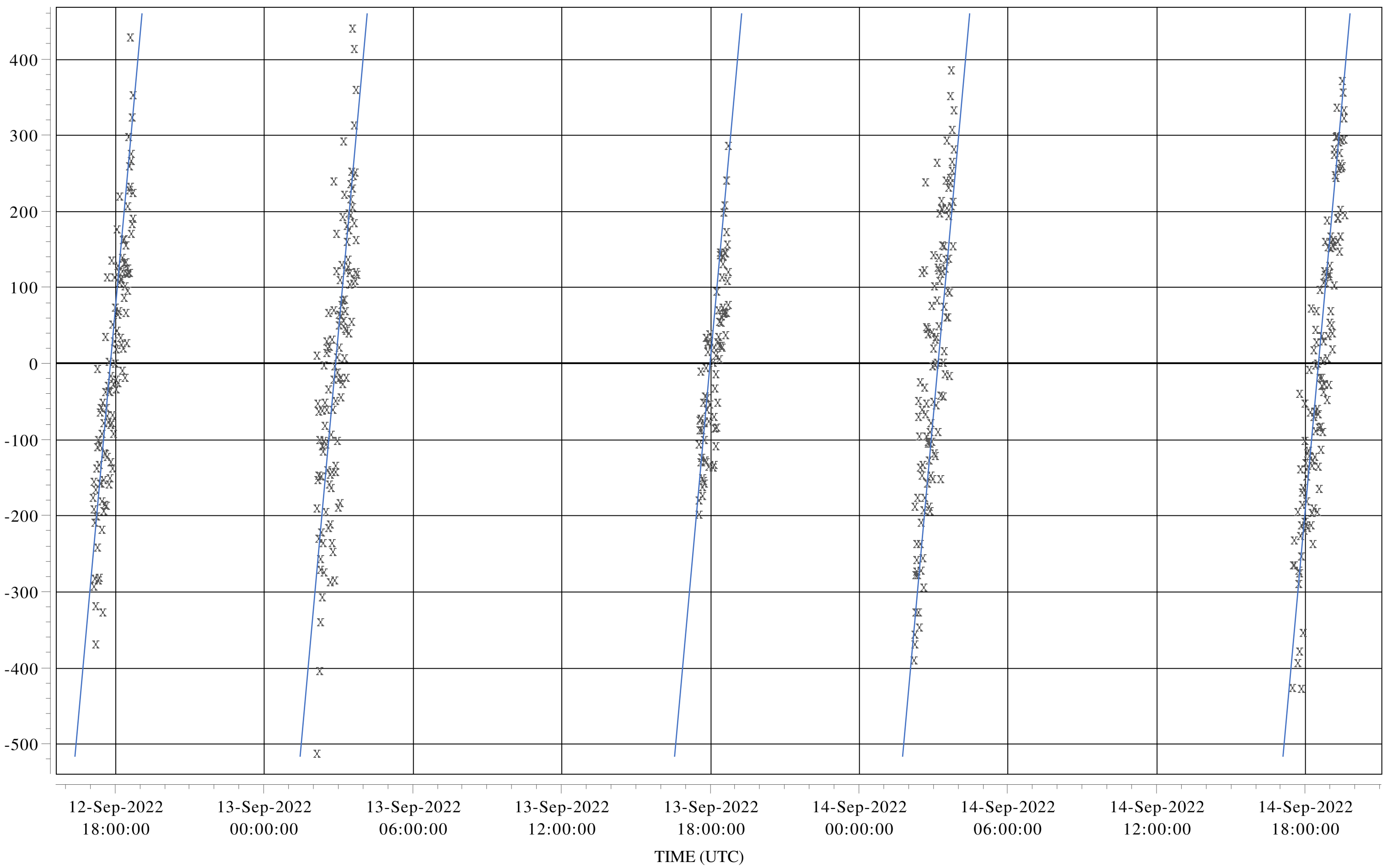

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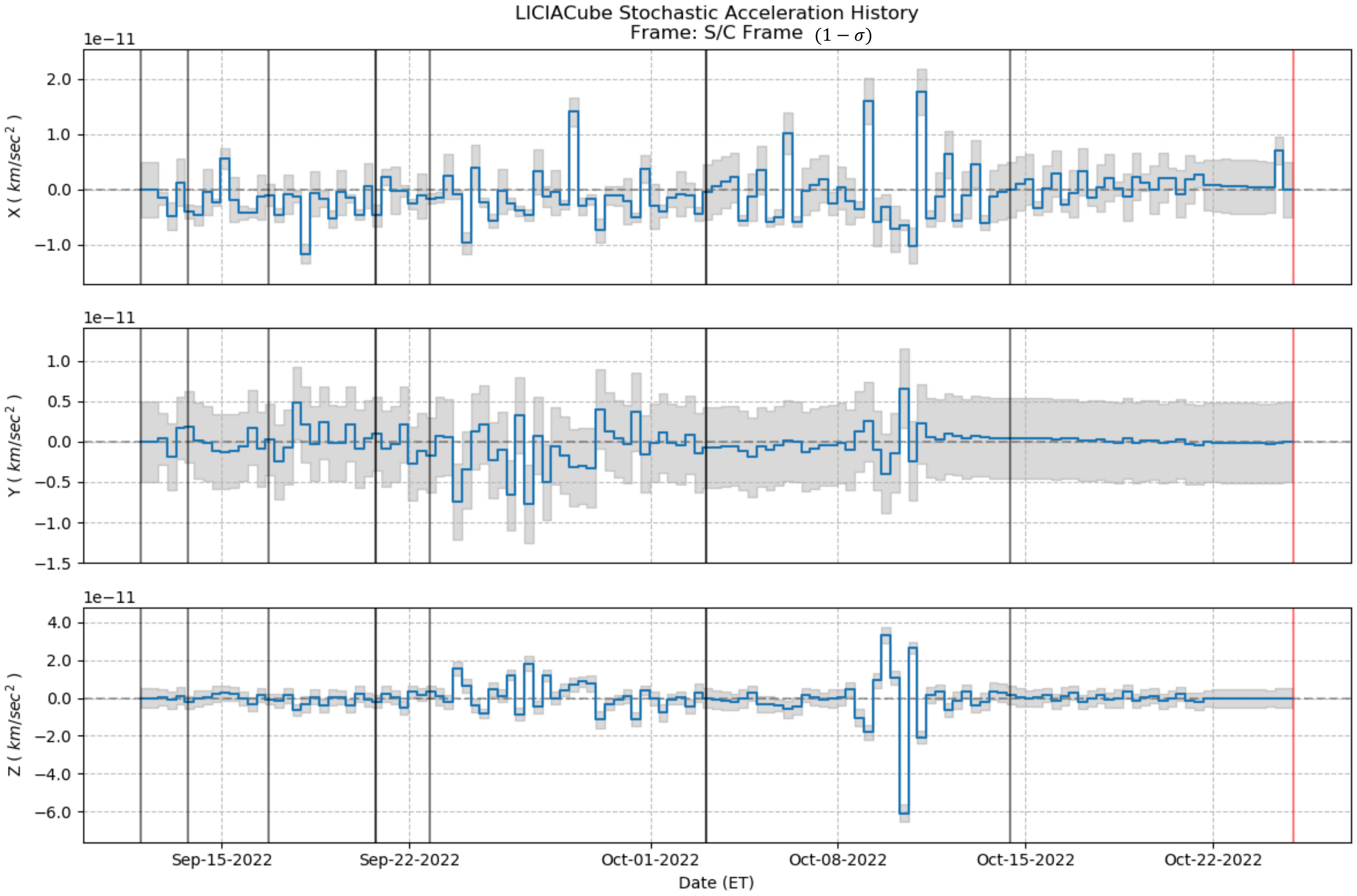
Stochastic accelerations during the mission



- Stochastic accelerations estimated.
  - White noise, 8h batch.
  - A priori 10^{-11} km/sec^2.
  - Larger than expected.
- Problems increased when more attitude turns were performed.
- More desaturation maneuvers than expected.
- Gas Leaks were discarded.
- Hypothesis: Large non-gravitational acc.
  - Solar radiation pressure?
  - Thermal radiation pressure?

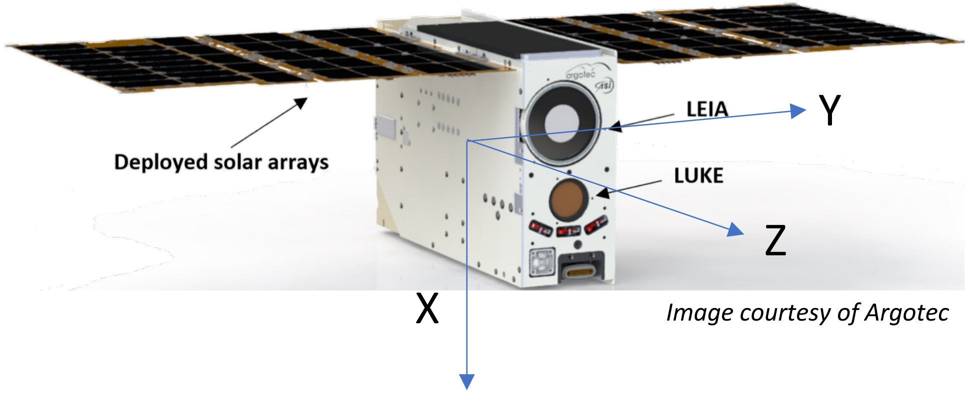


Image courtesy of Argotec

Challenges and Lessons

- Performance of the propulsion system: Overall good. Only 2 orbital maneuvers to reach the target.
- Transponder: Overall really good accuracies. As good as any other large S/C.
  - Challenge: Residual Doppler bias potentially inducing errors in the solution.
  - Well characterized through the range data.
- Large non-gravitational accelerations.
  - We needed to change the strategy of the stochastics during the operations.
  - More desaturation maneuvers were required.
- Payload had some unexpected problems with the lenses.
  - Required severe postprocessing. Not good for NAV. OK for science.
- Given the platform limitations related to the COTS hardware employed, the navigation process is challenging when dealing with strong navigation requirements.
  - Not optimal systems, not redundant, they are cheaper.

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All the NAV requirements were satisfied.

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Thanks for your attention!

Questions?

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Acknowledgments:

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